



US010951105B2

(12) **United States Patent**  
**Dai et al.**

(10) **Patent No.:** **US 10,951,105 B2**  
(45) **Date of Patent:** **Mar. 16, 2021**

(54) **GEARED SPHERICAL ELECTROMAGNETIC MACHINE WITH TWO-AXIS ROTATION**

(56) **References Cited**

U.S. PATENT DOCUMENTS

(71) Applicant: **HONEYWELL INTERNATIONAL INC.**, Morris Plains, NJ (US)

3,183,725 A \* 5/1965 Frye ..... G01C 19/20  
74/5.7

(72) Inventors: **Zhijun Dai**, Shanghai (CN); **Chao Wang**, Shanghai (CN)

4,610,172 A \* 9/1986 Mickle ..... G01C 19/24  
250/231.12

(73) Assignee: **HONEYWELL INTERNATIONAL INC.**, Charlotte, NC (US)

4,628,765 A \* 12/1986 Dien ..... B25J 17/0275  
74/665 A

(\*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 158 days.

5,533,418 A \* 7/1996 Wu ..... B25J 9/102  
248/181.1

(21) Appl. No.: **16/381,744**

7,675,208 B2 \* 3/2010 Bandera ..... H02K 7/14  
310/80

(22) Filed: **Apr. 11, 2019**

7,905,463 B2 3/2011 Burnham et al.

(65) **Prior Publication Data**

US 2020/0328667 A1 Oct. 15, 2020

7,969,375 B2 6/2011 Blalock

8,080,911 B2 12/2011 Won et al.

9,000,628 B1 \* 4/2015 Ho ..... H02K 41/031  
310/36

10,326,348 B2 \* 6/2019 Bandera ..... H02K 41/031

2004/0232790 A1 11/2004 Mendenhall

2009/0230787 A1 \* 9/2009 Won ..... H02K 41/03  
310/38

2010/0207488 A1 \* 8/2010 Ting ..... H02N 2/16  
310/323.06

2013/0127285 A1 \* 5/2013 Yano ..... H02K 41/031  
310/156.43

2017/0012482 A1 \* 1/2017 Bandera ..... H02K 1/27

2017/0012492 A1 \* 1/2017 Bandera ..... H02K 41/031

(Continued)

(51) **Int. Cl.**

**H02K 41/06** (2006.01)

**H02K 7/08** (2006.01)

**H02K 13/00** (2006.01)

**H02K 7/116** (2006.01)

(52) **U.S. Cl.**

CPC ..... **H02K 41/065** (2013.01); **H02K 7/08** (2013.01); **H02K 7/116** (2013.01); **H02K 13/003** (2013.01); **H02K 2201/18** (2013.01)

(58) **Field of Classification Search**

CPC .... H02K 41/031; H02K 2201/18; H02K 7/02; H02K 15/08

USPC ..... 310/38, 82, 156.43, 179, 323.06  
See application file for complete search history.

FOREIGN PATENT DOCUMENTS

CN 102029614 B 5/2012

EP 3249794 A2 11/2017

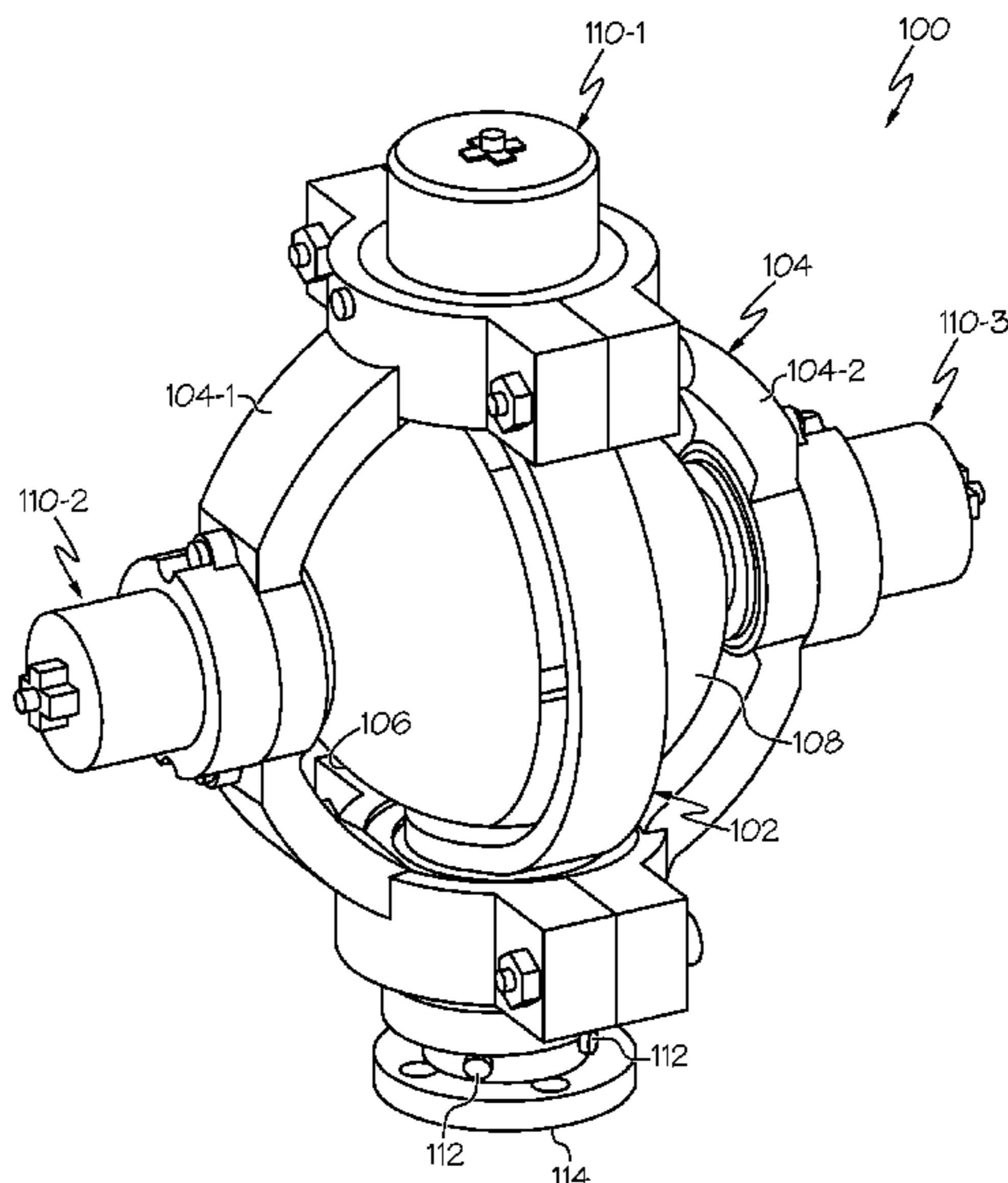
*Primary Examiner* — Jose A Gonzalez Quinones

(74) *Attorney, Agent, or Firm* — Lorenz & Kopf, LLP

(57) **ABSTRACT**

A geared spherical electromagnetic machine with two-axis rotation includes an inner frame, an outer frame, a spherical body, a first coil, a second coil, a third coil, a first hemispherical body, a second hemispherical body, a first plurality of inner magnets, a second plurality of inner magnets, a first gearbox, and a second gearbox.

**19 Claims, 6 Drawing Sheets**



(56)

**References Cited**

U.S. PATENT DOCUMENTS

2017/0040861 A1\* 2/2017 Ho ..... H02K 15/08  
2017/0349298 A1\* 12/2017 Tian ..... G03B 17/561  
2018/0273212 A1\* 9/2018 Zhu ..... G01C 19/24

\* cited by examiner

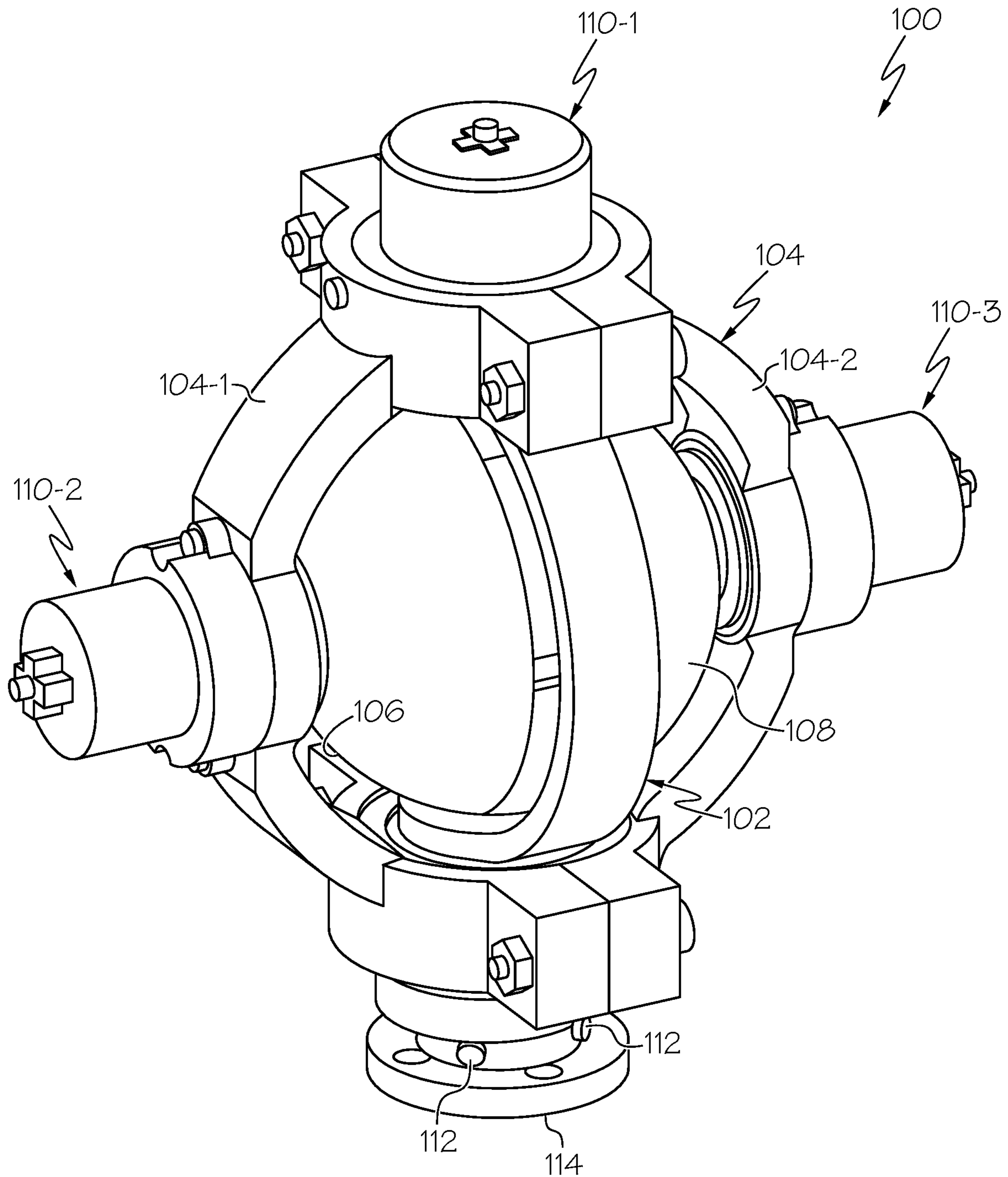


FIG. 1

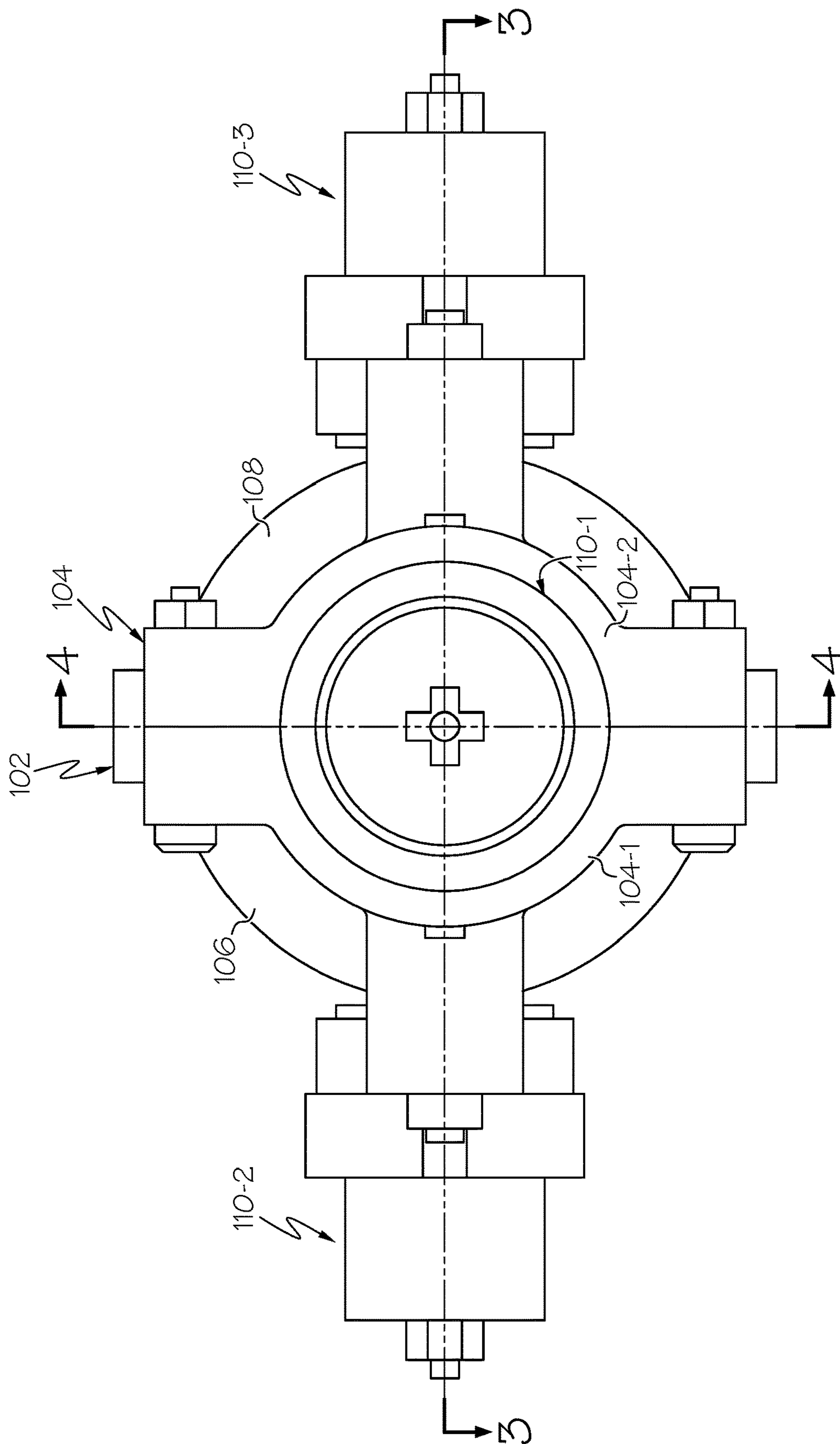
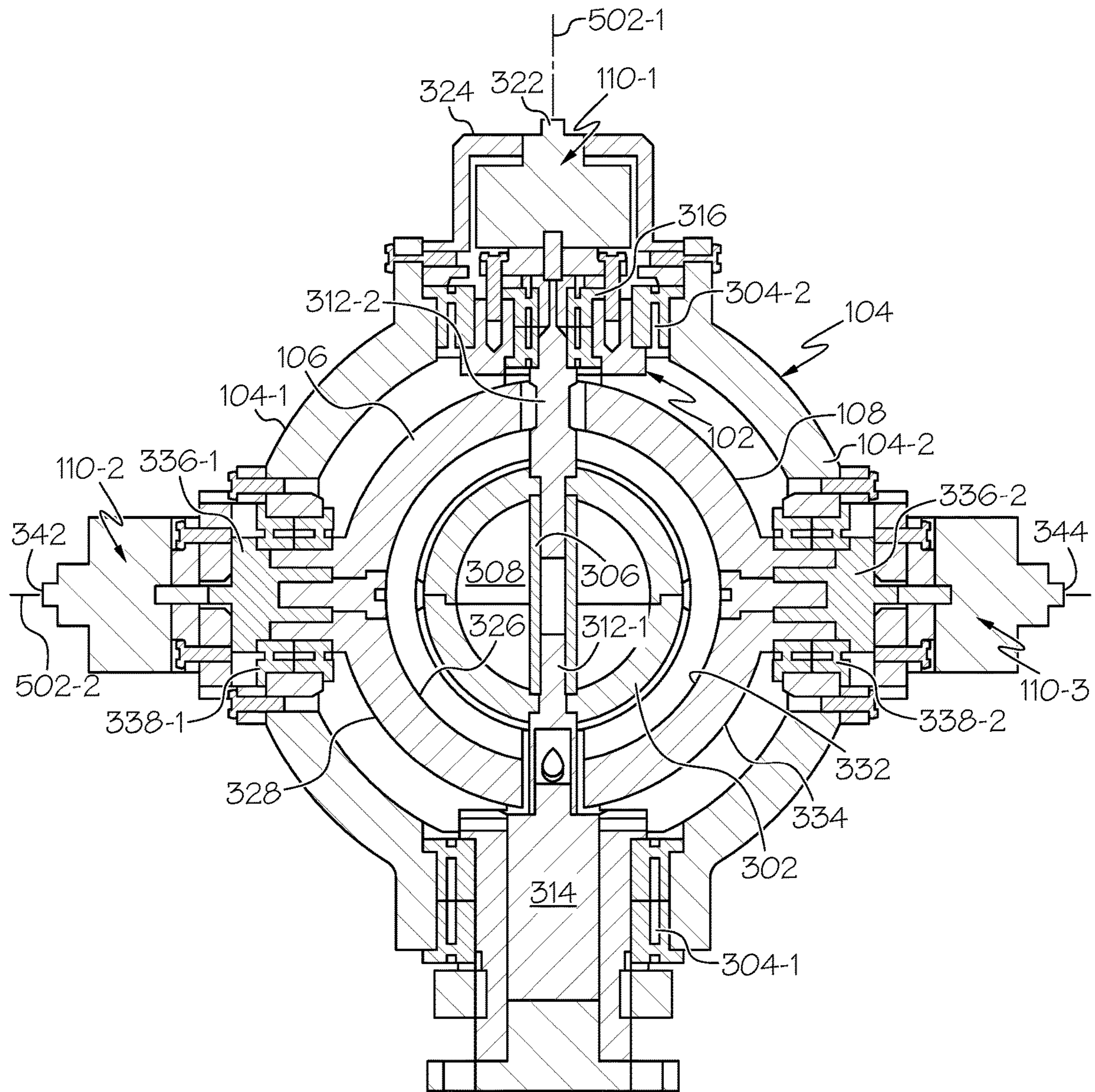


FIG. 2



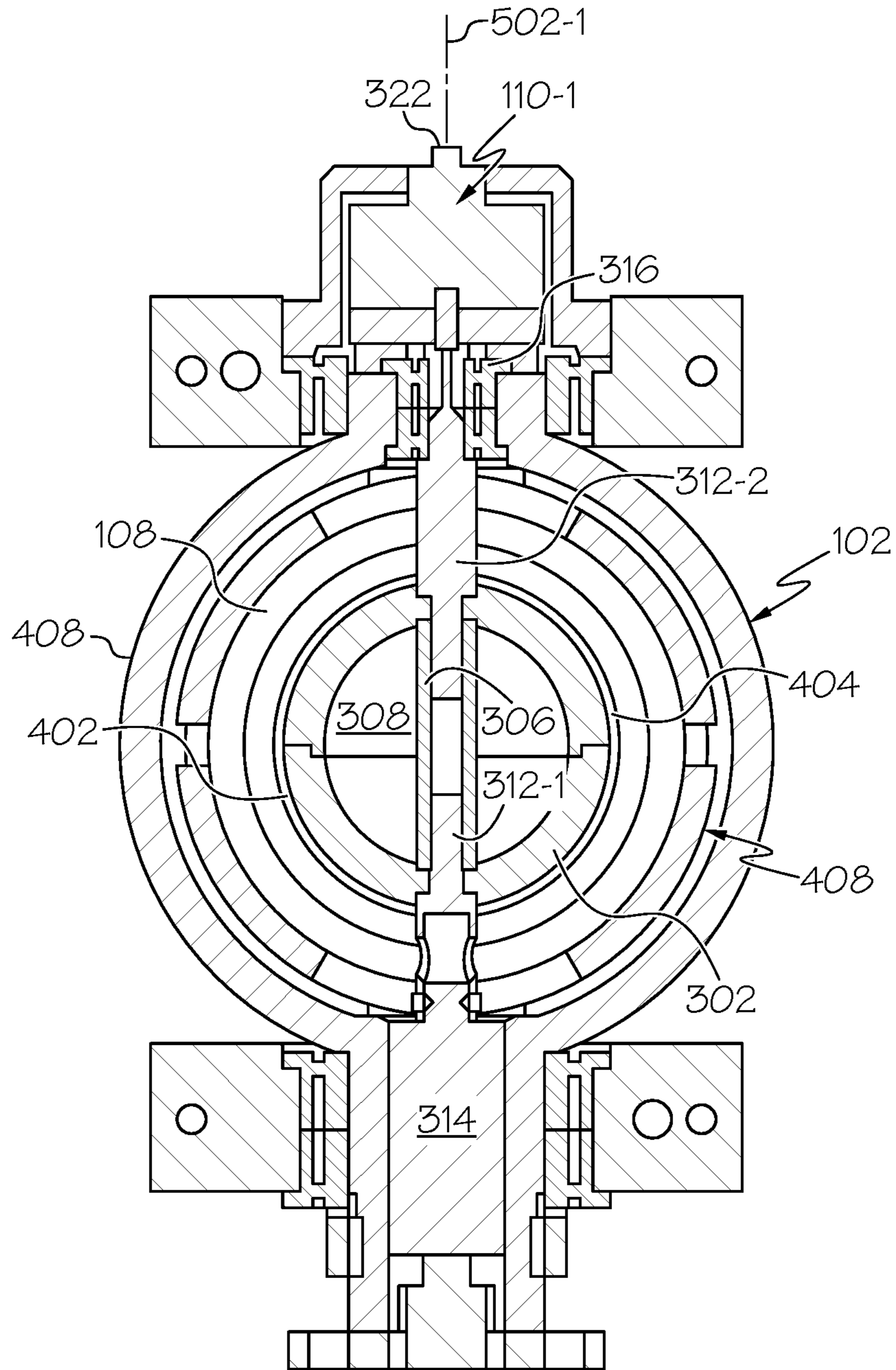


FIG. 4

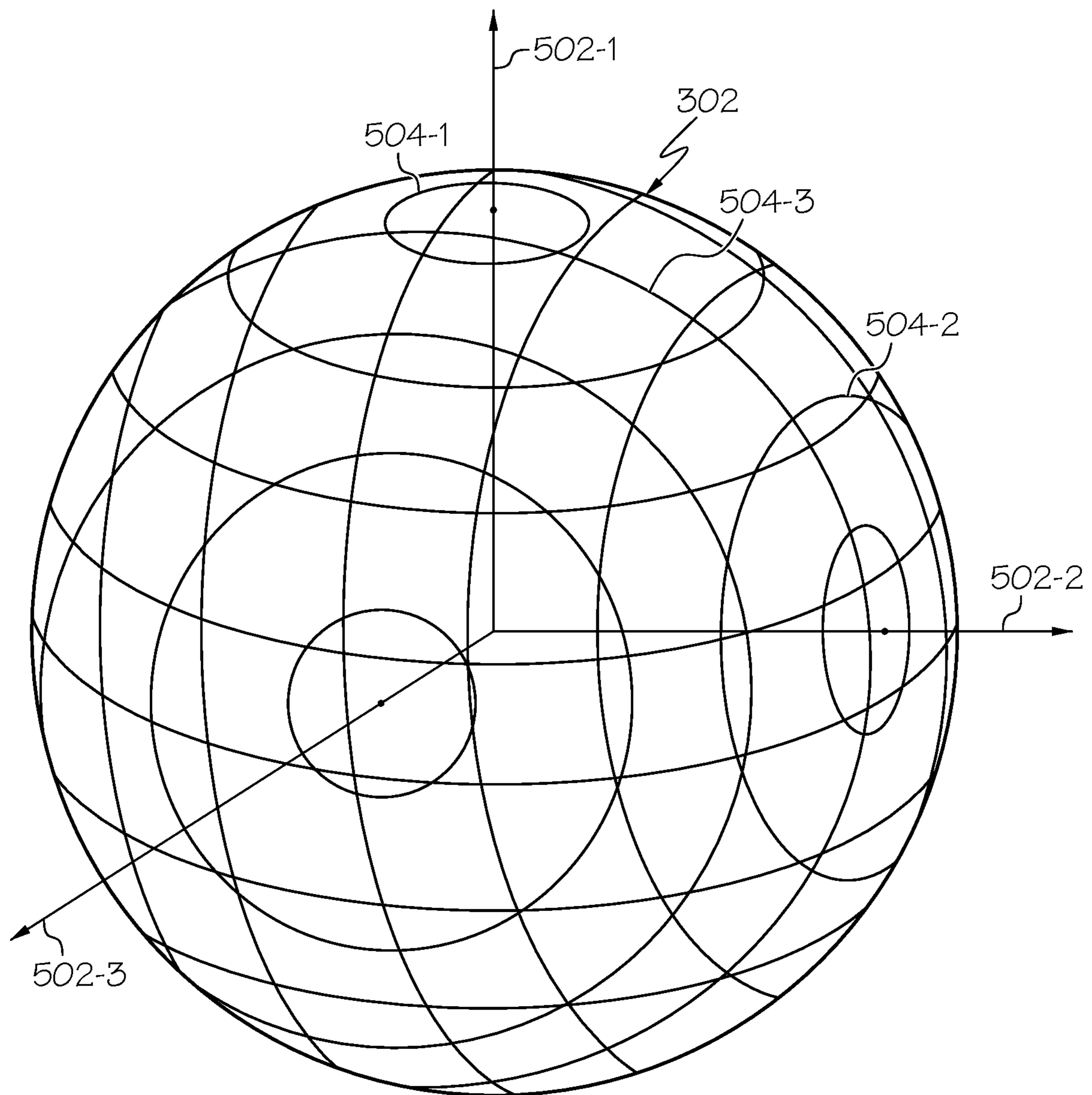


FIG. 5

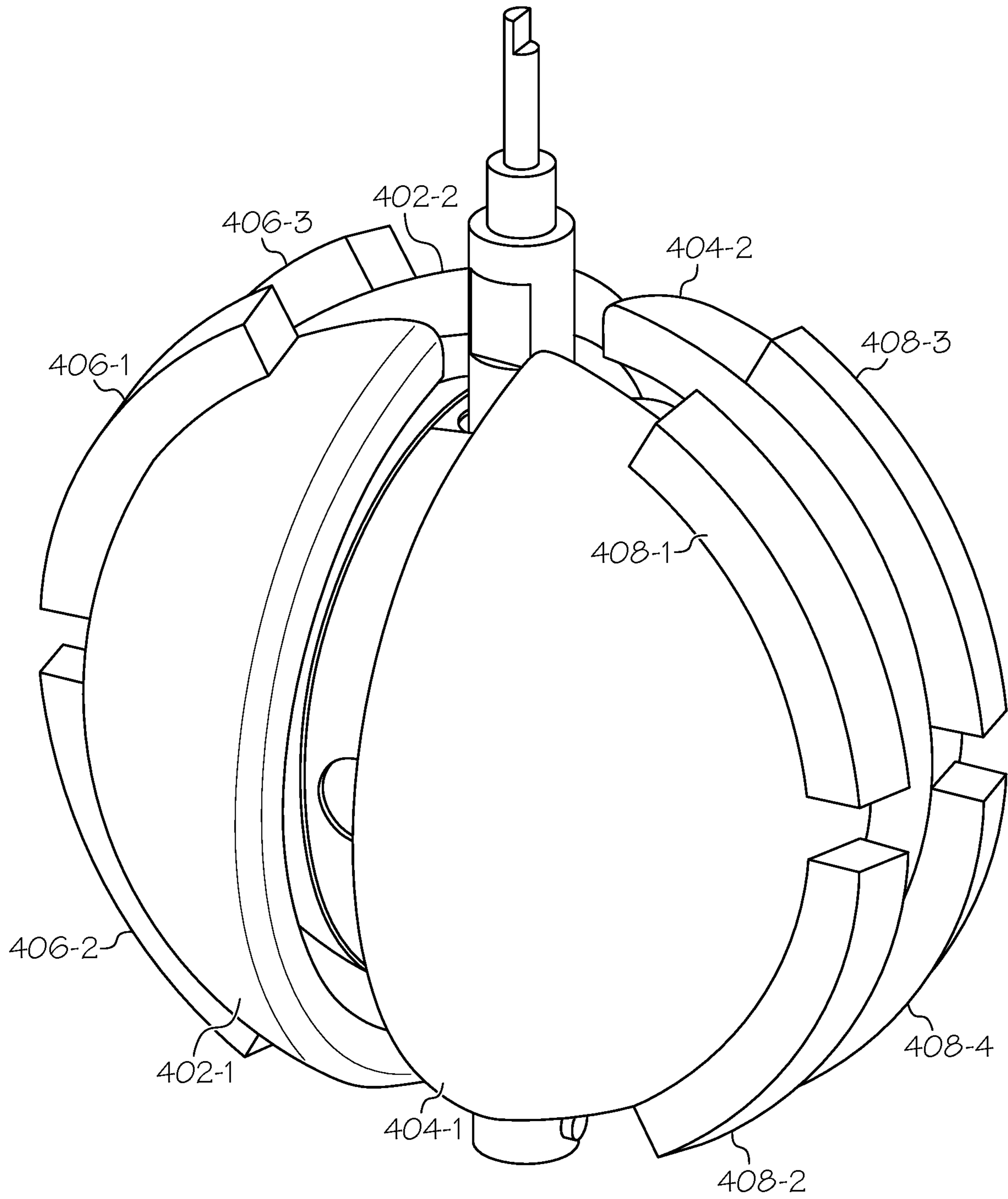


FIG. 6



1

## GEARED SPHERICAL ELECTROMAGNETIC MACHINE WITH TWO-AXIS ROTATION

### TECHNICAL FIELD

The present invention generally relates to electromagnetic machines, and more particularly relates to a geared spherical electromagnetic machine with two-axis rotation.

### BACKGROUND

It is generally known that currently available motion control systems that are designed to move an object in more than one degree of freedom (DoF) include a separate motor or actuator for each DoF. More specifically, at least two motors or actuators are needed to implement 2-DoF motion, at least three motors or actuators are needed to implement 3-DoF motion, and so on. Consequently, mechanisms that involve more than one DoF tend to be somewhat large and cumbersome, and therefore inefficient.

Various attempts have been made to develop electromagnetic machines (e.g., motors) that can rotate in multiple degrees-of-freedom. For example, various spherical motor configurations have been developed. However, the spherical motors heretofore developed suffer certain drawbacks. For example, the spherical motors presently known supply relatively low output torque. As such, these spherical motors cannot be implemented in systems that rely on relatively high output torque.

Hence, there is a need for a spherical electromagnetic machine that can supply the relatively higher output torque requirements of many industrial applications. The present invention addresses at least this need.

### BRIEF SUMMARY

This summary is provided to describe select concepts in a simplified form that are further described in the Detailed Description. This summary is not intended to identify key or essential features of the claimed subject matter, nor is it intended to be used as an aid in determining the scope of the claimed subject matter.

In one embodiment, a geared spherical electromagnetic machine with two-axis rotation includes an inner frame, an outer frame, a spherical body, a first coil, a second coil, a third coil, a first hemispherical body, a second hemispherical body, a first plurality of inner magnets, a second plurality of inner magnets, a first gearbox, and a second gearbox. The outer frame disposed adjacent to, and configured to rotate relative to, the inner frame. The spherical body has a first axis of symmetry, a second axis of symmetry, and a third axis of symmetry. The first, second, and third axes of symmetry are disposed perpendicular to each other. The spherical body is rotationally coupled to the inner frame, and is rotatable, relative to the inner frame and the outer frame, about the first axis of symmetry. The first coil is wound on the spherical armature about the first axis of symmetry, the second coil is wound on the spherical armature about the second axis of symmetry, and the third coil is wound on the spherical armature about the third axis of symmetry. The first hemispherical body is spaced apart from, and surrounds a first portion of, the spherical body. The first hemispherical body is rotationally coupled to the outer frame, and is rotatable, relative to the inner frame, the outer frame, and the spherical body, about the second axis of symmetry. The first hemispherical body includes a first hemispherical body inner surface and a first hemispherical body outer surface. The second hemispherical body is spaced apart from, and surrounds a second portion of, the spherical body. The second hemispherical body is rotationally coupled to the outer frame, and is rotatable, relative to the inner frame, the outer frame, and the spherical body, about the second axis of symmetry. The second hemispherical body includes a second hemispherical body inner surface and a second hemispherical body outer surface. The first plurality of inner magnets is coupled to the first hemispherical body inner surface, and the second plurality of inner magnets is coupled to the second hemispherical body inner surface. The first gearbox is mounted on the inner frame and is coupled to the spherical body, the second gearbox is mounted on the outer frame and is coupled to the first hemispherical body, and the third gearbox is mounted on the outer frame and coupled to the second hemispherical body. The first, second, and third gearbox each have a gear ratio greater than 1.0.

2

second hemispherical body is spaced apart from, and surrounds a second portion of, the spherical body. The second hemispherical body is rotationally coupled to the outer frame, and is rotatable, relative to the inner frame, the outer frame, and the spherical body, about the second axis of symmetry. The second hemispherical body includes a second hemispherical body inner surface and a second hemispherical body outer surface. The first plurality of inner magnets is coupled to the first hemispherical body inner surface, and the second plurality of inner magnets is coupled to the second hemispherical body inner surface. The first gearbox is mounted on the inner frame and is coupled to the spherical body, and the second gearbox is mounted on the outer frame and is coupled to the first hemispherical body.

In another embodiment, a geared spherical electromagnetic machine with two-axis rotation includes an inner frame, an outer frame, a spherical body, a first coil, a second coil, a third coil, a first hemispherical body, a second hemispherical body, a first plurality of inner magnets, a second plurality of inner magnets, a first gearbox, a second gearbox, and a third gearbox. The outer frame disposed adjacent to, and configured to rotate relative to, the inner frame. The spherical body has a first axis of symmetry, a second axis of symmetry, and a third axis of symmetry. The first, second, and third axes of symmetry are disposed perpendicular to each other. The spherical body is rotationally coupled to the inner frame, and is rotatable, relative to the inner frame and the outer frame, about the first axis of symmetry. The first coil is wound on the spherical armature about the first axis of symmetry, the second coil is wound on the spherical armature about the second axis of symmetry, and the third coil is wound on the spherical armature about the third axis of symmetry. The first hemispherical body is spaced apart from, and surrounds a first portion of, the spherical body. The first hemispherical body is rotationally coupled to the outer frame, and is rotatable, relative to the inner frame, the outer frame, and the spherical body, about the second axis of symmetry. The first hemispherical body includes a first hemispherical body inner surface and a first hemispherical body outer surface. The second hemispherical body is spaced apart from, and surrounds a second portion of, the spherical body. The second hemispherical body is rotationally coupled to the outer frame, and is rotatable, relative to the inner frame, the outer frame, and the spherical body, about the second axis of symmetry. The second hemispherical body includes a second hemispherical body inner surface and a second hemispherical body outer surface. The first plurality of inner magnets is coupled to the first hemispherical body inner surface, and the second plurality of inner magnets is coupled to the second hemispherical body inner surface. The first gearbox is mounted on the inner frame and is coupled to the spherical body, the second gearbox is mounted on the outer frame and is coupled to the first hemispherical body, and the third gearbox is mounted on the outer frame and coupled to the second hemispherical body. The first, second, and third gearbox each have a gear ratio greater than 1.0.

In yet another embodiment, a geared spherical electromagnetic machine with two-axis rotation includes an inner frame, an outer frame, a spherical body, a first coil, a second coil, a third coil, a first hemispherical body, a second hemispherical body, a first plurality of inner magnets, a first plurality of outer magnets, a second plurality of inner magnets, a second plurality of outer magnets, a first gearbox, a second gearbox, a third gearbox, first, second, and third shafts, and first, second, and third bearing assemblies. The outer frame disposed adjacent to, and configured to rotate

3

relative to, the inner frame. The spherical body has a first axis of symmetry, a second axis of symmetry, and a third axis of symmetry. The first, second, and third axes of symmetry are disposed perpendicular to each other. The spherical body is rotationally coupled to the inner frame, and is rotatable, relative to the inner frame and the outer frame, about the first axis of symmetry. The first coil is wound on the spherical armature about the first axis of symmetry, the second coil is wound on the spherical armature about the second axis of symmetry, and the third coil is wound on the spherical armature about the third axis of symmetry. The first hemispherical body is spaced apart from, and surrounds a first portion of, the spherical body. The first hemispherical body is rotationally coupled to the outer frame, and is rotatable, relative to the inner frame, the outer frame, and the spherical body, about the second axis of symmetry. The first hemispherical body includes a first hemispherical body inner surface and a first hemispherical body outer surface. The second hemispherical body is spaced apart from, and surrounds a second portion of, the spherical body. The second hemispherical body is rotationally coupled to the outer frame, and is rotatable, relative to the inner frame, the outer frame, and the spherical body, about the second axis of symmetry. The second hemispherical body includes a second hemispherical body inner surface and a second hemispherical body outer surface. The first plurality of inner magnets is coupled to the first hemispherical body inner surface, and the first plurality of outer magnets is coupled to the first hemispherical body outer surface. The second plurality of inner magnets is coupled to the second hemispherical body inner surface, and the second plurality of outer magnets is coupled to the second hemispherical body outer surface. The first gearbox is mounted on the inner frame and is coupled to the spherical body, the second gearbox is mounted on the outer frame and is coupled to the first hemispherical body, and the third gearbox is mounted on the outer frame and coupled to the second hemispherical body. The first shaft is coupled to the spherical body and the first gearbox, and the first bearing is disposed between the first shaft and the inner frame. The second shaft is coupled to the first hemispherical body and the second gearbox, and the second bearing is disposed between the second shaft and the outer frame. The third shaft is coupled to the second hemispherical body and the third gearbox, and the third bearing is disposed between the third shaft and the outer frame.

Furthermore, other desirable features and characteristics of the geared spherical electromagnetic machine will become apparent from the subsequent detailed description and the appended claims, taken in conjunction with the accompanying drawings and the preceding background.

#### BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will hereinafter be described in conjunction with the following drawing figures, wherein like numerals denote like elements, and wherein:

FIG. 1 depicts a perspective view of one embodiment of a geared spherical electromagnetic machine;

FIG. 2 depicts a top view (FIG. 2) of the geared spherical electromagnetic machine of FIG. 1;

FIG. 3 depicts a cross section view of the geared spherical electromagnetic machine of FIG. 1 taken along line 3-3 in FIG. 2;

FIG. 4 depicts a cross section view of the geared spherical electromagnetic machine of FIG. 1 taken along line 4-4 in FIG. 2;

4

FIG. 5 depicts a perspective view of an embodiment of a spherical body with orthogonally arranged coils wound thereon; and

FIG. 6 depicts the relative positions of the various magnets that are used to implement the spherical electromagnetic machine of FIG. 1, but with portions of the machine removed for clarity.

#### DETAILED DESCRIPTION

The following detailed description is merely exemplary in nature and is not intended to limit the invention or the application and uses of the invention. As used herein, the word “exemplary” means “serving as an example, instance, or illustration.” Thus, any embodiment described herein as “exemplary” is not necessarily to be construed as preferred or advantageous over other embodiments. All of the embodiments described herein are exemplary embodiments provided to enable persons skilled in the art to make or use the invention and not to limit the scope of the invention which is defined by the claims. Furthermore, there is no intention to be bound by any expressed or implied theory presented in the preceding technical field, background, brief summary, or the following detailed description.

Referring first to FIGS. 1-4, a perspective view (FIG. 1), a top view (FIG. 2), a cross section view taken along line 3-3 in FIG. 2 (FIG. 3), and a cross section view taken along line 4-4 in FIG. 2 (FIG. 4), respectively, of one embodiment of a geared spherical electromagnetic machine 100 with two-axis rotation is depicted. The depicted spherical machine 100 includes an inner frame 102, an outer frame 104, a spherical body 302 (not visible in FIGS. 1 and 2), a first hemispherical body 106, a second hemispherical body 108, and a plurality of gearboxes 110 (e.g., 110-1, 110-2, 110-3). Although three gearboxes 110 are included in the depicted embodiment, it will be appreciated that the spherical machine 100 could be implemented with less than this number of gearboxes.

The inner frame 102 is fixedly coupled, via suitable mounting hardware 112, to a mounting flange 114. The mounting flange 114 is configured, using suitable non-illustrated hardware, to be fixedly mounted to a surface. In this manner, when the geared spherical electromagnetic machine 100 is mounted, via the mounting flange 114, to a surface, the inner frame 102 is mounted against rotation. The inner frame 102, at least in the depicted embodiment, is implemented as a single integral structure. It will be appreciated that this is merely exemplary and that the inner frame 102 could be implemented using multiple parts, if needed or desired.

The outer frame 104 is disposed adjacent to, and is configured to rotate relative to, the inner frame 102. To implement this functionality, and as FIG. 3 depicts more clearly, a plurality of bearing assemblies 304—referred to herein, for convenience, as a lower bearing assembly 304-1 and an upper bearing assembly 304-2—are disposed between the inner frame 102 and outer frame 104. The bearing assemblies 304 may be implemented using any one of numerous types of bearing assemblies. Some non-limiting examples include any one of numerous types of ball bearing assemblies or sliding bearing assemblies. As FIGS. 1-3 also depict, the outer frame 104, at least in the depicted embodiment, is implemented using two frame halves—a first frame half 104-1 and a second frame half 104-2. It will be appreciated that this is merely exemplary and that the outer frame 104 could be implemented using more or less than this number of parts, if needed or desired.

## 5

The spherical body **302**, which is shown more clearly in FIG. **5**, has three perpendicularly disposed axes of symmetry—a first axis of symmetry **502-1**, a second axis of symmetry **502-2**, and a third axis of symmetry **502-3**. The spherical body **302** additionally has a plurality of coils **504** wound thereon. In the depicted embodiment, these include a first coil **504-1**, a second coil **504-2**, and a third coil **504-3**. It will be appreciated, however, that in some embodiments the geared spherical electromagnetic machine **100** may be implemented with only two coils instead of three. The first coil **504-1** is wound on the spherical body **302** about the first axis of symmetry **502-1**, the second coil **504-2** is wound on the spherical body **302** about the second axis of symmetry **502-2**, and the third coil **504-3**, when included, is wound on the spherical body **302** about the third axis of symmetry **502-3**. It should be noted that a sphere has an infinite number of axes of symmetry. Thus, the first, second, and third axes of symmetry **502-1**, **502-2**, **502-3**, could be any one of these axes of symmetry, so long as all three axes of symmetry are perpendicular to each other.

The spherical body **302** is rotatable, relative to both the inner frame **102** and the outer frame **104**, about the first axis of symmetry **502-1**. To do so, the spherical body **302**, at least in the depicted embodiment, is implemented using two hollow hemispherical portions that are joined together, with each half including a connector portion that extends radially inwardly. Thus, as FIGS. **3** and **4** depict, when assembled, the spherical body **302** includes a connector tube **306** that extends across the inner volume **308** of the spherical body **302**. A pair of shafts **312**—referred to herein for convenience as a lower shaft **312-1** and an upper shaft **312-2**—extend into different ends of, and engage, the connector tube **306**. Thus, rotation of the spherical body **302**, and concomitantly the connector tube **306**, results in rotation of the shafts **312**.

The lower shaft **312-1** is coupled to a slip ring **314**, which is in turn coupled to the mounting flange **114**. The slip ring **314**, as is generally known, transfers electrical power to the coils **504** wound on the spherical body **302**. The upper shaft **312-2** extends through an inner bearing assembly **316**, which is disposed between the upper shaft **312** and the inner frame **102** and which may be implemented using any one of numerous ball bearing assemblies or sliding bearing assemblies. The upper shaft **312-2** is also coupled to one of the gearboxes **110** (the first gearbox **110-1**).

The first gearbox **110-1** is mounted on, via suitable mounting hardware, the inner frame **102**. The first gearbox **110-1** includes a first gearbox output shaft **322** that receives the torque from the spherical body **302**, via the upper shaft **312-2**, when the spherical body **302** rotates. The first gearbox output shaft **322** extends through an opening in, and engages, a first gearbox cover **324**. The first gearbox cover **324** is fixedly coupled to the outer frame **104**. Thus, when the spherical body **302** rotates about the first axis of symmetry **502-1**, the outer frame **104** also rotates about the first axis of symmetry **502-1**. However, due to the gear ratio of the first gearbox **110-1** (discussed further below), the speed at which the outer frame **104** rotates will be less than that of the spherical body **302**, but the output torque is greater.

Turning now to the other portions of the machine **100**, it is seen that the first hemispherical body **106** is spaced apart from, and surrounds a first portion of, the spherical body **302**, and includes a first hemispherical body inner surface **326** and a first hemispherical body outer surface **328**. The second hemispherical body **108** is spaced apart from, and surrounds a second portion of, the spherical body **302**, and includes a second hemispherical body inner surface **332** and a second hemispherical body outer surface **334**. The first

## 6

hemispherical body **106** and the second hemispherical body **108** are both rotationally coupled to the outer frame **104**, and are both rotatable, about the second axis of symmetry **502-2**, relative to the inner frame **102**, the outer frame **102**, and the spherical body **302**. To implement this functionality, the machine **100** additionally includes two shaft assemblies **336**—referred to herein for convenience as a first shaft assembly **336-1** and a second shaft assembly **336-2**—and two outer frame bearing assemblies **338**—referred to herein for convenience as a first outer frame bearing assembly **338-1** and a second outer frame bearing assembly **338-2**.

The first shaft assembly **336-1** is coupled to the first hemispherical body **106**, via suitable hardware, and is rotationally mounted on the first outer frame bearing assembly **338-1**, which is in turn coupled to the outer frame **104**. The first shaft assembly **336-1** is coupled to a second gearbox **110-2**, which is mounted on the outer frame **104**. The second shaft assembly **336-2** is coupled to the second hemispherical body **108**, via suitable hardware, and is rotationally mounted on the second outer frame bearing assembly **338-2**, which is also coupled to the outer frame **104**. The second shaft assembly **336-2** is coupled to a third gearbox **110-3**, which is mounted on the outer frame **104**. The second and third gearboxes **110-2**, **110-3** have second and third gearbox output shafts **342**, **344**, respectively, which are coupled to a non-illustrated payload.

With the above-described configuration, when the first and second hemispherical bodies **106**, **108** rotate about the second axis of symmetry **502-2**, the second and third gearbox output shafts **342**, **344** also rotate. However, due to the gear ratio of the second and third gearboxes **110-2**, **110-3** (discussed further below), the speed at which the second and third gearbox output shafts **342**, **344** rotate will be less than that of the first and second hemispherical bodies **106**, **108**, but the output torques are greater.

Referring now to FIG. **4**, it is seen that a first plurality of inner magnets **402** is coupled to the first hemispherical body inner surface **326**, and a second plurality of inner magnets **404** is coupled to the second hemispherical body inner surface **332**. Although the first and second plurality of inner magnets **402**, **404** may vary in shape and number and configuration, in the depicted embodiment, each is shaped like a fraction of a hemisphere (e.g., wedge-shaped), and there are four total inner magnets—two first inner magnets **402-1**, **402-2** and two second inner magnets **404-1**, **404-2**—not all of which are visible in FIG. **4**.

In some embodiments, it may be desirable to include additional magnets. These additional magnets, when included, provide a coupling force that ensures the first and second hemispherical bodies **102**, **104** rotate synchronously. These additional magnets, which are included in the depicted embodiment, are coupled to the first and second hemispherical body outer surfaces **328**, **334**, and are thus referred to herein as outer magnets. In particular, the depicted machine **100** includes a first plurality of outer magnets **406** and a second plurality of outer magnets **408**. Each of the first plurality of outer magnets **406** is coupled to the first hemispherical body outer surface **328**, and each of the second plurality of outer magnets **408** is coupled to the second hemispherical body outer surface **334**. Although the first and second plurality of outer magnets **406**, **408** may vary in shape and number and configuration, in the depicted embodiment, each is arc shaped, and there are eight total outer magnets—four first outer magnets **406-1**, **406-2**, **406-3**, **406-4** and four second outer magnets **408-1**, **408-2**, **408-3**, **408-4**—not all of which are visible in FIG. **4**.

Before proceeding further, FIG. 6 is included herewith to provide added clarity regarding the configuration and relative positions of each of the inner **402**, **404** and outer **406**, **408** magnets. In this figure, the relative positions of the inner **402**, **404** and outer **406**, **408** magnets are shown with the first and second first and second hemispherical bodies **106**, **108** being removed, although the spherical body **302** is depicted. It should be noted that one of the second outer magnets (e.g., **408-4**) is not visible in FIG. 6, but its placement is understood to those skilled in the art.

Because of the configuration of the coils **502** and the magnets **402**, **404**, **406**, **408**, when an electrical current is supplied to one or more of the coils **502**, a Lorentz force is generated between the energized coil(s) **502** and the magnets **402**, **404**, **406**, **408**, which in turn generates in a torque about one or more of the axes of symmetry **504**. The direction of the generated torque, as may also be appreciated, is based on the direction of the current flow in the coil(s) **502**.

In particular, the spherical body **302**, and thus the outer frame **103**, can be made to rotate about the first axis of symmetry **502-1** by controllably energizing the second and third coils **504-2**, **504-3** with alternating electrical currents that are equal in amplitude and 90-degrees out of phase. The first and second hemispherical bodies **106**, **108** can be made to rotate about the second axis of symmetry **502-2** by controllably energizing the first and third coils **504-1**, **504-3** with alternating electrical currents that are equal in amplitude and 90-degrees out of phase.

It was previously noted that the gear ratios of the gearboxes **110** is such that the output torque of the electromagnetic machine **100** is increased. More specifically, and as may be appreciated, the gearboxes each have gear ratio greater than 1.0. Thus, the output torque of the spherical body **302** and/or the first and second hemispherical bodies **106**, **108** is increase by an amount proportional to the gear ratio. For example, if the output torque before the gearboxes **110** is 16.3 millinewton meter, and the gear ratio is 150, the output torque after the gearbox is about 2.4 newton meter.

The spherical electromagnetic machine **100** described herein supplies relatively higher output torque as compared to presently known spherical electromagnetic machines.

In this document, relational terms such as first and second, and the like may be used solely to distinguish one entity or action from another entity or action without necessarily requiring or implying any actual such relationship or order between such entities or actions. Numerical ordinals such as "first," "second," "third," etc. simply denote different singles of a plurality and do not imply any order or sequence unless specifically defined by the claim language. The sequence of the text in any of the claims does not imply that process steps must be performed in a temporal or logical order according to such sequence unless it is specifically defined by the language of the claim. The process steps may be interchanged in any order without departing from the scope of the invention as long as such an interchange does not contradict the claim language and is not logically nonsensical.

Furthermore, depending on the context, words such as "connect" or "coupled to" used in describing a relationship between different elements do not imply that a direct physical connection must be made between these elements. For example, two elements may be connected to each other physically, electronically, logically, or in any other manner, through one or more additional elements.

While at least one exemplary embodiment has been presented in the foregoing detailed description of the invention, it should be appreciated that a vast number of variations exist. It should also be appreciated that the exemplary

embodiment or exemplary embodiments are only examples, and are not intended to limit the scope, applicability, or configuration of the invention in any way. Rather, the foregoing detailed description will provide those skilled in the art with a convenient road map for implementing an exemplary embodiment of the invention. It being understood that various changes may be made in the function and arrangement of elements described in an exemplary embodiment without departing from the scope of the invention as set forth in the appended claims.

What is claimed is:

**1.** A geared spherical electromagnetic machine with two-axis rotation, comprising:

an inner frame;

an outer frame disposed adjacent to, and configured to rotate relative to, the inner frame;

a spherical body having a first axis of symmetry, a second axis of symmetry, a third axis of symmetry, the first, second, and third axes of symmetry disposed perpendicular to each other, the spherical body rotationally coupled to the inner frame, the spherical body rotatable, relative to the inner frame and the outer frame, about the first axis of symmetry;

a first coil wound on the spherical armature about the first axis of symmetry;

a second coil wound on the spherical armature about the second axis of symmetry;

a third coil wound on the spherical armature about the third axis of symmetry;

a first hemispherical body spaced apart from, and surrounding a first portion of, the spherical body, the first hemispherical body rotationally coupled to the outer frame, the first hemispherical body rotatable, relative to the inner frame, the outer frame, and the spherical body, about the second axis of symmetry, the first hemispherical body including a first hemispherical body inner surface and a first hemispherical body outer surface;

a second hemispherical body spaced apart from, and surrounding a second portion of, the spherical body, the second hemispherical body rotationally coupled to the outer frame, the second hemispherical body rotatable, relative to the inner frame, the outer frame, and the spherical body, about the second axis of symmetry, the second hemispherical body including a second hemispherical body inner surface and a second hemispherical body outer surface;

a first plurality of inner magnets coupled to the first hemispherical body inner surface;

a second plurality of inner magnets coupled to the second hemispherical body inner surface;

a first gearbox mounted on the inner frame and coupled to the spherical body; and

a second gearbox mounted on the outer frame and coupled to the first hemispherical body.

**2.** The geared spherical electromagnetic machine of claim **1**, further comprising:

a third gearbox mounted on the outer frame and coupled to the second hemispherical body.

**3.** The geared spherical electromagnetic machine of claim **2**, wherein the first, second, and third gearbox each have a gear ratio greater than 1.0.

**4.** The geared spherical electromagnetic machine of claim **1**, wherein each of the inner magnets is shaped like a fraction of a hemisphere.

**5.** The geared spherical electromagnetic machine of claim **1**, further comprising:

9

a first plurality of outer magnets coupled to the first hemispherical body outer surface; and  
 a second plurality of outer magnets coupled to the second hemispherical body outer surface.

6. The geared spherical electromagnetic machine of claim 5, wherein each of the first plurality of outer magnets and each of the second plurality of outer magnets is arc shaped.

7. The geared spherical electromagnetic machine of claim 1, further comprising:  
 a first shaft coupled to the spherical body and the first gearbox; and  
 a first bearing disposed between the first shaft and the inner frame.

8. The geared spherical electromagnetic machine of claim 7, further comprising:  
 a second shaft coupled to the spherical body;  
 a mounting flange fixedly coupled to the inner frame and adapted to be fixedly mounted to a structure; and  
 a slip ring coupled to the second shaft and the mounting flange.

9. The geared spherical electromagnetic machine of claim 8, further comprising:  
 a second shaft coupled to the first hemispherical body and the second gearbox; and  
 a second bearing disposed between the second shaft and the outer frame.

10. The geared spherical electromagnetic machine of claim 9, further comprising:  
 a third shaft coupled to the second hemispherical body and the third gearbox; and  
 a third bearing disposed between the third shaft and the outer frame.

11. A geared spherical motor with two-axis rotation, comprising:  
 an inner frame;  
 an outer frame disposed adjacent to, and configured to rotate relative to, the inner frame;  
 a spherical body having a first axis of symmetry, a second axis of symmetry, a third axis of symmetry, the first, second, and third axes of symmetry disposed perpendicular to each other, the spherical body rotationally coupled to the inner frame, the spherical body rotatable, relative to the inner frame and the outer frame, about the first axis of symmetry;  
 a first coil wound on the spherical armature about the first axis of symmetry;  
 a second coil wound on the spherical armature about the second axis of symmetry;  
 a third coil wound on the spherical armature about the third axis of symmetry;  
 a first hemispherical body spaced apart from, and surrounding a first portion of, the spherical body, the first hemispherical body rotationally coupled to the outer frame, the first hemispherical body rotatable, relative to the inner frame, the outer frame, and the spherical body, about the second axis of symmetry, the first hemispherical body including a first hemispherical body inner surface and a first hemispherical body outer surface;  
 a second hemispherical body spaced apart from, and surrounding a second portion of, the spherical body, the second hemispherical body rotationally coupled to the outer frame, the second hemispherical body rotatable, relative to the inner frame, the outer frame, and the spherical body, about the second axis of symmetry, the second hemispherical body including a second hemispherical body inner surface and a second hemispherical body outer surface;

10

a first plurality of inner magnets coupled to the first hemispherical body inner surface;  
 a second plurality of inner magnets coupled to the second hemispherical body inner surface;  
 a first gearbox mounted on the inner frame and coupled to the spherical body;  
 a second gearbox mounted on the outer frame and coupled to the first hemispherical body; and  
 a third gearbox mounted on the outer frame and coupled to the second hemispherical body,  
 wherein the first, second, and third gearbox each have a gear ratio greater than 1.0.

12. The spherical motor of claim 11, wherein each of the inner magnets is shaped like a fraction of a hemisphere.

13. The spherical motor of claim 11, further comprising:  
 a first plurality of outer magnets coupled to the first hemispherical body outer surface; and  
 a second plurality of outer magnets coupled to the second hemispherical body outer surface.

14. The spherical motor of claim 13, wherein each of the first plurality of outer magnets and each of the second plurality of outer magnets is arc shaped.

15. The geared spherical electromagnetic machine of claim 11, further comprising:  
 a first shaft coupled to the spherical body and the first gearbox; and  
 a first bearing disposed between the first shaft and the inner frame.

16. The geared spherical electromagnetic machine of claim 15, further comprising:  
 a second shaft coupled to the spherical body;  
 a mounting flange fixedly coupled to the inner frame and adapted to be fixedly mounted to a structure; and  
 a slip ring coupled to the second shaft and the mounting flange.

17. The geared spherical electromagnetic machine of claim 16, further comprising:  
 a second shaft coupled to the first hemispherical body and the second gearbox; and  
 a second bearing disposed between the second shaft and the outer frame.

18. The geared spherical electromagnetic machine of claim 17, further comprising:  
 a third shaft coupled to the second hemispherical body and the third gearbox; and  
 a third bearing disposed between the third shaft and the outer frame.

19. A geared spherical motor with two-axis rotation, comprising:  
 an inner frame;  
 an outer frame disposed adjacent to, and configured to rotate relative to, the inner frame;  
 a spherical body having a first axis of symmetry, a second axis of symmetry, a third axis of symmetry, the first, second, and third axes of symmetry disposed perpendicular to each other, the spherical body rotationally coupled to the inner frame, the spherical body rotatable, relative to the inner frame and the outer frame, about the first axis of symmetry;  
 a first coil wound on the spherical armature about the first axis of symmetry;  
 a second coil wound on the spherical armature about the second axis of symmetry;  
 a third coil wound on the spherical armature about the third axis of symmetry;  
 a first hemispherical body spaced apart from, and surrounding a first portion of, the spherical body, the first

**11**

hemispherical body rotationally coupled to the outer frame, the first hemispherical body rotatable, relative to the inner frame, the outer frame, and the spherical body, about the second axis of symmetry, the first hemispherical body including a first hemispherical body inner surface and a first hemispherical body outer surface;

a second hemispherical body spaced apart from, and surrounding a second portion of, the spherical body, the second hemispherical body rotationally coupled to the outer frame, the second hemispherical body rotatable, relative to the inner frame, the outer frame, and the spherical body, about the second axis of symmetry, the second hemispherical body including a second hemispherical body inner surface and a second hemispherical body outer surface;

a first plurality of inner magnets coupled to the first hemispherical body inner surface;

a first plurality of outer magnets coupled to the first hemispherical body outer surface;

a second plurality of inner magnets coupled to the second hemispherical body inner surface;

**12**

a second plurality of outer magnets coupled to the second hemispherical body outer surface;

a first gearbox mounted on the inner frame and coupled to the spherical body;

a second gearbox mounted on the outer frame and coupled to the first hemispherical body;

a third gearbox mounted on the outer frame and coupled to the second hemispherical body;

a first shaft coupled to the spherical body and the first gearbox;

a first bearing disposed between the first shaft and the inner frame;

a second shaft coupled to the first hemispherical body and the second gearbox;

a second bearing disposed between the second shaft and the outer frame;

a third shaft coupled to the second hemispherical body and the third gearbox; and

a third bearing disposed between the third shaft and the outer frame.

\* \* \* \* \*